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Art. V.—*The Geology of the Port Campbell District.*

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Abstract.

In the coastal cliffs east and west of Port Campbell township, Middle Tertiary calcareous clays and limestones are assigned a (?) Balcombian age, while underlying deposits between Glenample Steps and a locality ¾-mile N.W. of the Gellibrand River are classed with the Balcombian from palaeontological and lithological correlation with beds of that age described from other parts of Victoria. Balcombian and (?) Balcombian sediments outcrop for over 15 miles along the coast, are from 750′-1,000′ thick, and conformably overlie a thin series (60′-100′) of deposits composed of grit, conglomerate, limestone and calcareous clay, probably of Janjukian age. Unfossiliferous beds beneath and conformable with the Janjukian sediments may be Oligocene. The sediments are principally horizontal with occasional gentle undulations and a few small faults. They dip down to form a broad, shallow syncline in the west of the area, and have low westerly dips in the south-east. The Balcombian, Janjukian and (?) Oligocene deposits are apparently conformable with westerly dipping Eocene rocks which occur south-east of the Gellibrand River and unconformably overstep Jurassic rocks. The general indications in the Tertiary beds are that an uninterrupted sequence of deposition occurred from Eocene to Balcombian times, after which this theatre of sedimentation was elevated to form a land mass. Post-Miocene clays form a thin veneer on the Middle Tertiary rocks. Pleistocene dune limestone has infilled the valley of the pre-Pleistocene ancestor of the Gellibrand River. Recent deposits occur along present river courses, at the base of the coastal cliffs in parts of the area and across the mouths of the larger watercourses.

Introduction.

The Port Campbell district is situated on the south-west coast of Victoria. The area investigated constitutes the coastal strip of the southern portion of the county of Heytesbury, and stretches from Peterborough in the west to a point two and a half miles south-east of Princetown (fig. 1).

The oldest Tertiary rocks of the area are exposed in the sea-cliffs at Pebble Point in the south-east. They are grits and sandy ironstones of Eocene age, overlain by fossiliferous clays and sandstones which are also probably Eocene (1, 30, 33). Unfossiliferous ferruginous and carbonaceous sandstones above the Eocene beds may be of Oligocene age. This series of deposits occurs S.E. of the Gellibrand River.

Fossiliferous limestones, argillaceous limestones and calcareous clays of Miocene age outcrop extensively to the west and north-west of the Gellibrand River. They are soft rocks which form

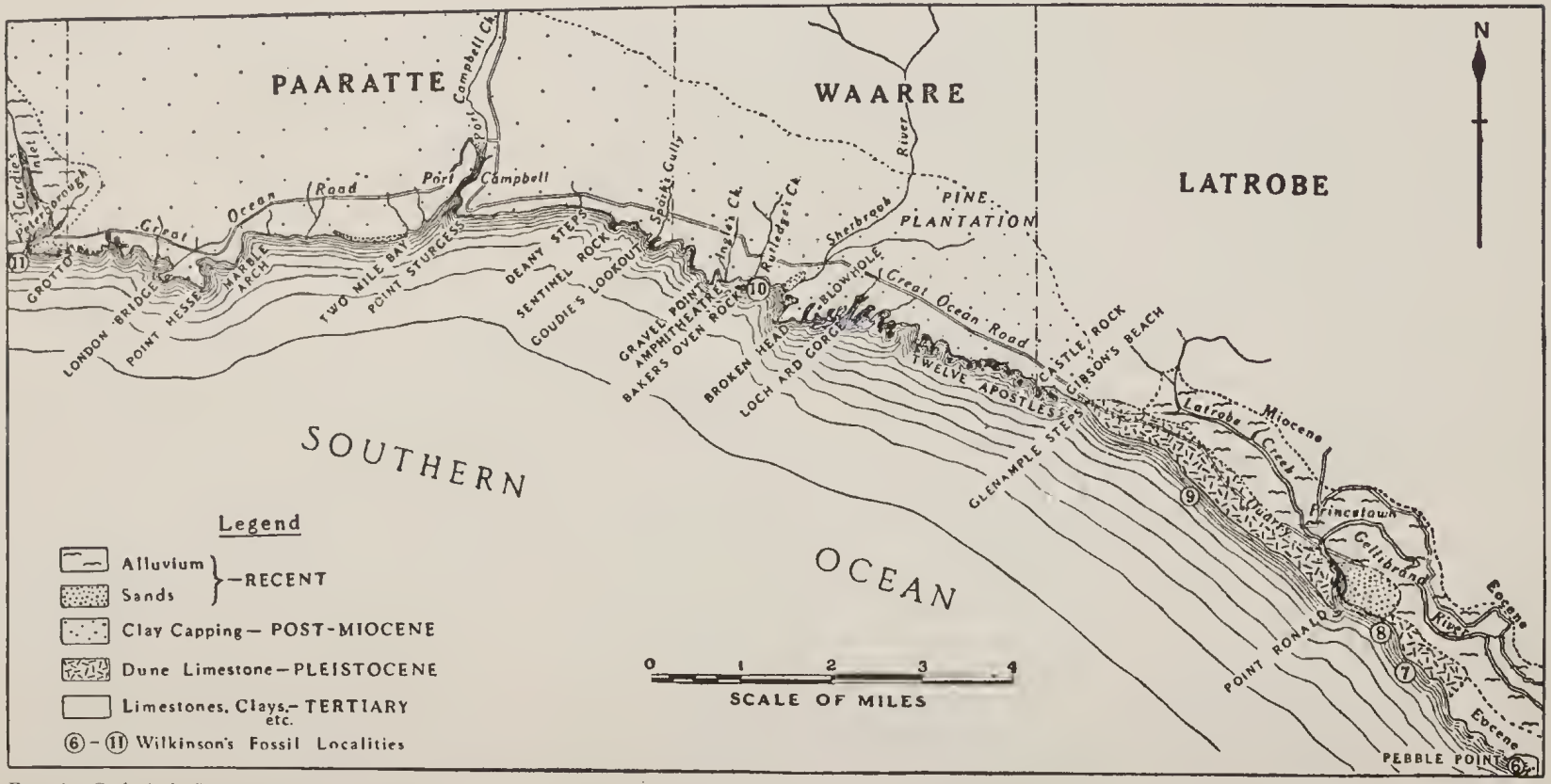

FIG 1.—Geological Sketch Map of the Peterborough–Port Campbell–Princetown Coastal Area, showing place names. Outline compiled from State Parish Plans in the County of Heytesbury.

the high, vertical cliffs so characteristic of the coastline from Glenample Steps (fig. 1) to Peterborough.

The basal members of the Tertiary deposits, i.e., the Eocene beds, rest unconformably, with some overstepping, upon an erosion surface in Jurassic arkoses and mudstones which form widespread outcrops in the Cape Otway Peninsula.

The Miocene beds are classified principally with the Balcombian series from the results of detailed investigations of the foraminiferal content of various members of the deposits by Mr. W. J. Parr (see appendix), and from the preliminary examination of the molluscan fauna by Dr. F. A. Singleton.

A veneer of clays on the Tertiary deposits is regarded as of post-Miocene age. The vertical nature of the cliffs in the district renders many parts of the Tertiary exposures inaccessible. Nevertheless, such portions of the cliffs as could be studied provide considerable evidence of the age sequences in the Tertiary succession. The Tertiary rocks of the coastal sections in the immediate vicinity of Princetown are partially obscured by considerable thicknesses of Pleistocene dune limestone for a distance of approximately 4 miles. This portion of the area represents an infilled valley of the ancestor of the Gellibrand River. Recent, partially fixed calcareous sand dunes have been built up on the consolidated Pleistocene dune limestone in this part of the area, and also on eroded Tertiary rocks at the mouths of the Curdie and Sherbrook Rivers. Behind river-mouth sand dunes and beach sand-ridges along the coast, deposits of sand and alluvium have accumulated, more particularly upon the valley floors of Port Campbell Creek, the Sherbrook and Gellibrand Rivers and Curdie's Inlet. The Recent deposits of the Gellibrand River and of Curdie's Inlet contain shallow-water marine, as well as fluviatile, sediments.

Previous Work.

The area was originally surveyed by C. S. Wilkinson in 1865, when all of the Tertiary rocks in the district were regarded as Lower Miocene in age (34). The accompanying section (fig. 2) was prepared by Mr. A. E. Kennedy, of the Victorian Mines Department, from the original by Wilkinson. It has not been published previously, and portrays, with a considerable degree of accuracy, the general relationships of the Mesozoic, Tertiary and post-Tertiary rocks from Moonlight Head in the south-east, to Warrnambool in the west. This section embraces the Peterborough-Port Campbell-Princetown coastal sections, recent investigations of which show a few minor departures from Wilkinson's original work. The numbers on the section refer to Wilkinson's fossil localities. The vertical scale, not noted by Wilkinson, is approximately $\frac{1}{8}'' = 250$ feet.

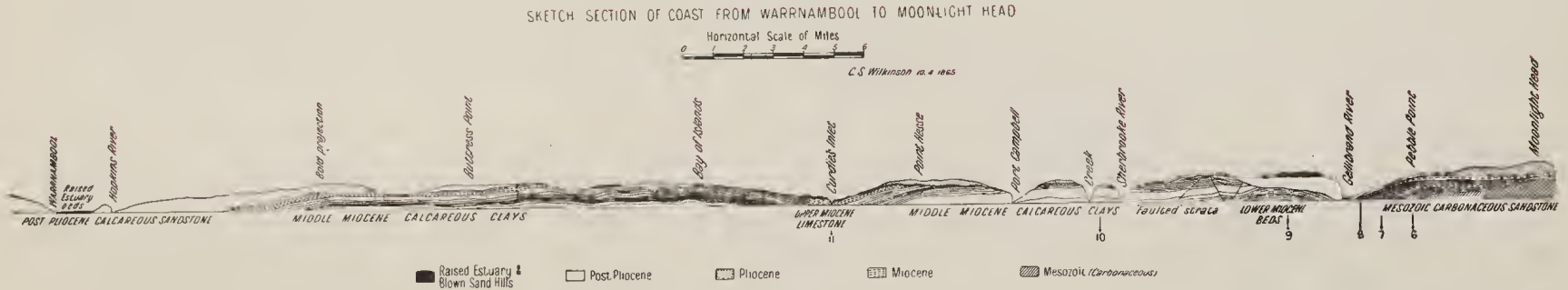

FIG. 2.—Wilkinson's Section from Moonlight Head to Warrnambool.

In 1868, H. M. Jenkins examined fossils collected from the area, and classified the beds immediately N.W. of the mouth of the Gellibrand River as Miocene, stating that the most important bed was a dark, slate-coloured, stiff clay, very rich in fossils and remarkable for yielding perhaps the finest examples of Cypraea which occur in the fossil condition. Jenkins regarded deposits near the Sherbrook River (at a locality now known as the Rutledge's Creek coastal section), from which he recorded *Trigonia lamarcki*, as probably being referable to the same horizon as the Mordialloc deposits in Port Phillip Bay, characterized by the same form of Trigonia, and mapped as Lower Pliocene by the Victorian geological surveyors (19). It is now known, however, that this Trigonia at both these localities is not *Neotrigonia lamarcki*, a recent species from the New South Wales coast, but is *Neotrigonia acuticostata* (McCoy), a closely allied species described from Beaumaris.

In 1870, P. M. Duncan reproduced the results of elaborate surveys made by Victorian geologists, and described the corals collected from the deposits between the Gellibrand River and Moonlight Head (13). Later, he described the echinoids from various portions of the area (14).

In 1877, R. A. F. Murray included additional notes on this area in his report on the Cape Otway district (23), giving details concerning the marshy flats of the Gellibrand River, the dune rock at the mouth of this river, the age relations of some of the Tertiary deposits, and correlations with Tertiary outcrops in other parts of Victoria.

Various ages have been assigned to the Tertiary deposits of the Port Campbell and neighbouring coastal sections from time to time. Tate (31), Tate and Dennant (32), Pritchard (25, 26, 27 and 28), Maplestone (20, 21 and 22), Dennant and Kitson (12), Chapman (2-8), Hall (15, 16), Chapple (9, 10) and Parr and Collins (24) have described various fossils from the several component beds of the Tertiary deposits between Peterborough and Pebble Point. Most of these authors correlated individual fossils or suites of various groups of the invertebrate fossils with those found in other Victorian Tertiary deposits. The results of the correlations have varied as a consequence of changes in opinion concerning the general sequence of the Tertiary succession in Victoria. Recent ideas concerning this succession are set out by Singleton (29, pp. 63-64), and included in his table of correlation are some of the Tertiary deposits of the Port Campbell district.

The various opinions relating to the age of the Port Campbell Tertiary rocks are summarized in Table 1, where localities elsewhere in Victoria, with which certain of the Port Campbell strata have been correlated, are also tabulated.

TABLE 1.

Location of Beds.	Age.	Author.	Date.	Correlated Localities.
Deposits between Gellibrand River and Moonlight Head (= Pebble Point Beds)	Miocene ..	Duncan ..	1870	Beds at Aire River. Castle Cove. Locality 1 mile east of Point Addis
,, ,, ,,	Middle Tertiary (Miocene)	Murray ..	1877	
,, ,, ,,	Upper Eocene	Dennant and Kitson	1903	
,, ,, ,,	Barwonian (Balcombian)	Chapman ..	1904	
,, ,, ,,	Lower Janjuklan	Pritchard ..	1923	
,, ,, ,,	Eocene ..	Teichert, Singleton, Baker	1943	
Gellibrand Clays, 3 miles north-west of mouth of Gellibrand River	Lower Miocene	Wilkinson ..	1865	Orphan Asylum Reserve, Fyansford, near Geelong
,, ,, ,,	Miocene ..	Jenkins ..	1868	
,, ,, ,,	Lower Oligocene	McCoy ..	1874–1882	
,, ,, ,,	Eocene ..	Tate and Dennant	1893–1896	
,, ,, ,,	Lower Tertiary (Oligocene)	Murray ..	1877	Point 2 miles west of Cape Otway. East bank of Aire River. Coast between Aire River and Castle Cove. Coast between Mt. Eliza and Mt. Martha
Gellibrand Clays, 3 miles west of mouth of Gellibrand River	Upper Eocene	Tate ..	1899	
,, ,, ,,	Eocene ..	Pritchard ..	1901	
,, ,, ,,	Balcombian (Eocene)	Pritchard ..	1904	
,, ,, ,,	Barwonian (Eocene)	Tate and Dennant	1904	Muddy Creek (lower beds). Mornington.
,, ,, ,,	Janjukian (Miocene)	Chapman and Gabriel	1923	
,, ,, ,,	Janjukian (Miocene)	Chapman and Singleton	1925	
,, ,, ,,	Lower Miocene	Chapman and Crespin	1935	Basal beds at Sherbrook River, Lake Gnotuk and Lake Bullenmerri near Camperdown
,, ,, ,,	Balcombian (Middle Miocene)	Singleton ..	1940	Muddy Creek (lower beds). Mornington, Fyansford. Barwon River. Mitchell River. Lower part of Sorrento bore. Upper beds at Maude. Ironstones at Keilor and Royal Park (lower beds)
Loch Ard Gorge (Lower portion)	Middle Miocene	Chapman and Crespin	1935	Peterborough
Loch Ard Gorge (Upper portion)	Upper Miocene	Chapman and Crespin	1935	Lake Gilleah near Allansford. First and second creeks (Rutledge's and Ingle's) west of Sherbrook River
Sherbrook River ..	Eocene ..	Tate and Dennant	1893–1896	
,, ,,	Barwonian (Eocene)	Hall ..	1907	
,, ,,	Barwonian ..	Chapman ..	1914	European Miocene
Sherbrook River (Basal beds)	Lower Miocene	Chapman and Crespin	1935	Gellibrand River, near Princetown

TABLE 1.—*continued.*

Location of Beds.	Age.	Author.	Date.	Correlated Localities.
Creek 1 mile west of Sherbrook River (= Rutledge's Creek)	Lower Pliocene	Jenkins ..	1868	Mordialloc beds
,, ,, ,,	Middle Miocene	McCoy ..	1874–1882	
,, ,, ,,	Middle Miocene	Murray ..	1877	
,, ,, ,,	Janjukian (Miocene)	Chapman and Gabriel	1923	
,, ,, ,,	Janjukian (Miocene)	Chapman and Singleton	1925	
,, ,, ,,	Upper Miocene	Chapman and Crespin	1935	Lake Gilleah near Allansford
Rutledge's Creek (Upper beds)	Kalimnan (Lower Pliocene)	Chapman and Crespin	1935	Forsyth's (Grange Burn) McDonald's (Muddy Creek). Russell's Creek (Warrnambool). Portland (lower beds).
Rutledge's Creek (Lower beds)	Cheltenhamian (Upper Miocene)	Singleton ..	1940	Upper beds at Beaumaris. (?) Middle part of Sorrento bore
Port Campbell ..	Eocene ..	Tate and Dennant	1893–1896	
Two Mile Bay ..	Barwonian (Eocene)	Hall and Pritchard	1905	Curlewis (Oligocene of McCoy; Miocene of Chapman)
Curdie's Inlet ..	Miocene ..	Parr and Collins	1937	
Calcareous Sandrock, Gellibrand River	Post-Pliocene	Jenkins ..	1868	
,, ,,	Recent (Upper Pliocene)	Murray ..	1877	
Clays above Tertiary Rocks along coast, Port Campbell	Upper Tertiary	Murray ..	1877	

It can be seen from Table 1 that the clays of the Gellibrand River section have been classed by different authors into various stages of the Tertiary System—Eocene (26 and 32), Upper Eocene (31), Lower Oligocene (23), Oligocene (23), Lower Miocene (6), Middle Miocene (29) and Miocene (13, 34), while the beds stratigraphically higher than these clays (i.e., at Loch Ard Gorge, Sherbrook River and environs, &c.) have been variously placed in the Eocene (16), Lower Miocene (6), Middle Miocene (29), Upper Miocene (29) and Lower Pliocene (6). The correlation of the Gellibrand Clays (= Princetown Clays) with the Mornington and Muddy Creek (Lower) beds by Tate and Dennant (32) and by Murray (23), i.e., with beds regarded as belonging to the Balcombian marine stage of Tertiary sedimentation, is supported by the remarkable faunal and lithological similarities, although Murray (23) also correlated the Gellibrand Clays with beds at the Aire River and elsewhere along the Cape Otway coast, at localities where the beds are regarded as of (?)Janjukian age (Upper Oligocene to Lower Miocene) by Singleton (29). The beds near the mouth of the Sherbrook River (i.e., the coastal section at Rutledge's Creek) were correlated by Jenkins (19) with the Mordialloc (i.e., Beaumaris)

beds as Lower Pliocene. The upper layers of the deposits at Beaumaris have recently been classed as of Cheltenhamian (Upper Miocene) age (29).

The age assigned to the greater proportion of the Tertiary deposits N.W. of the Gellibrand River, from the present investigations, is Balcombian (Middle Miocene) and (?)Balcombian. The area, therefore, provides us with perhaps the finest and most extensive sections of Balcombian rocks yet recorded from Victoria. The following notes supply additional information concerning the nature of the Tertiary deposits and their fossil content. The mineralogical and petrological characters of the various rock types represented in the Port Campbell district have also been investigated.

Structural Features.

The Tertiary deposits of the coastal strip appear in the cliff sections between Peterborough in the west, and Glenample Steps in the east, mainly as a horizontal series of strata (Pl. II., figs. 1 and 3). Their horizontal disposition is accentuated by the formation of prominent, level, wave-cut platforms, wave-cut notches and storm benches, which have been developed along the bedding planes separating strata of slightly different solubility and hardness. The coast trends in a north-westerly direction in the eastern portion of the area, and east-west in the western portion. There is a general gentle seaward inclination (Pl. II., fig. 2) in the beds of up to 5°, as can be observed in transverse sections. At the Baker's Oven Rock and on the west side of the harbor at Port Campbell, dips of from 2° to 4° are present, while lower dips of about 1° occur at Loch Ard Gorge, London Bridge, in a bayside cliff west of the Amphitheatre, &c. The early geological survey officers, Wilkinson (34) and Murray (23), recorded the dip of the beds near the Gellibrand River (Pl. II., fig. 4) as 5° to the north-west, but Tate and Dennant recorded the dips as 4° in a west 12° south direction (32, p. 213). These are the maximum dips for the Tertiary beds west of the mouth of the Gellibrand River and east of Peterborough. Lower dip values result from the variable directions in which local coastal indentations cut across the direction of true dip. South-east of the mouth of the Gellibrand River, at small headlands in the vicinity of Pebble Point, the Eocene deposits dip at angles of 5° in much the same direction as the younger Tertiary sediments west of the river mouth (1). Low dips thus occur in the coastal sections both between Point Ronald (at the mouth of the Gellibrand River) and Pebble Point and between Point Ronald and Glenample Steps, but east and west of these localities the beds are more or less horizontal. Wilkinson recorded easterly dips in the Tertiary beds 40 chains west of the mouth of the Gellibrand River, and he considered that the Miocene strata 3

miles north-west of the river mouth occurred at the apex of an anticlinal curve (34, and see fig. 2). The author is unable to agree with these observations, having found that clays and sands 40 chains west of the Gellibrand River dip westerly 5° (Pl. III., fig. 12). No anticlinal structure was found 3 miles north-west of the Gellibrand River. The broad, shallow syncline at Peterborough, shown by Wilkinson in fig. 2, is proved by the disappearance of the Tertiary clays below sea level for about a mile on each side of Curdie's Inlet. Elsewhere in the coastal cliffs east and west of Peterborough, the clays form the lower 40′-60′ of the cliffs. The Curdie River apparently followed this synclinal structure.

The direction of elongation of certain of the rock stacks, gorges and heads of bays, and the trend of prominent cracks on wave-cut benches, indicate that some of the joint planes in the Tertiary rocks are parallel with the general trend of the coastline (i.e., N.W.-S.E. in the western part of the area). Others trend N.E.-S.W., parallel with other gorges and promontories in the central to eastern portion of the area. Some of the joint planes are vertical, and so control the nature of the cliff faces, others dip into the cliff faces at lower angles (e.g., west wall of Loch Ard Gorge, where the joints dip at 45°) and control the slope of the roofs of caves. Jointing in the Tertiary clays south-east of Glenample Steps is closely spaced, and appears to have resulted from recent alternate wetting and dessication of steeply inclined cliff faces (Pl. III., fig. 10).

Intraformational contortion in a band of highly plastic clay about 6 feet wide occurs among the dipping Tertiary series south-east of Glenample Steps (Pl. III., fig. 8). It can be traced for a few chains in the cliffs, and probably resulted from the movement of hydrated clays under the influence of the pressure of the overlying beds (18, Pl. 1), or from subaqueous slumping (18, p. 15).

Many of the bedding planes in the Tertiary rocks, especially those in the upper portions of the cliffs are marked by concentrations of nodules and sheets of secondary calcium carbonate (Pl. II., figs. 3 and 4), the nodules assuming rounded, cylindrical and irregular shapes.

The Tertiary beds throughout the area form an apparently conformable series, although, at Curdie's Inlet, Wilkinson stated that the soft, yellow limestone containing a few fossils, appeared to rest unconformably upon the underlying calcareous clays, since the limestone filled up small hollows in the upper beds of the calcareous clays (34). The Tertiary beds in the south-eastern portion of the area are unconformable to the Jurassic beds, while the base of the overlying non-stratified post-Miocene clays in the

western and central portions of the area is sharply delimited from the Tertiary deposits. The Pleistocene dune limestone rests unconformably upon Eocene, (?)Oligocene and Miocene sediments.

Wilkinson recorded numerous small faults in the cliff sections at Port Campbell; five or six were said to occur in a short distance (1 mile) (34). A few faults observed by the author are thrust faults; a small one in a cliff section north-west of Castle Rock has a stratigraphical throw of about 2 feet, and a hade of 25° in an east of south direction. Others of like nature occur in the cliffs west of Sherbrook River and in Thunder Cave at the head of Survey Gorge, half a mile west of Loch Ard Gorge. Minor variations in height of the more clearly-marked junctions between certain beds in less accessible portions of the cliff faces may be due to small faults, but may have resulted from local warping of the gently dipping strata.

In the western portion of the area, local sagging of the limestone beds in the vicinity of the Grotto has resulted in small-scale collapse structures (Pl. II., fig. 6). The motive force responsible for their development is gravity (17). The limestone has been bent and broken by slipping over calcareous clay deposits into caves dissolved in the underlying beds. Similar small-scale, monoclinal flexures are less clearly marked in the cliffs of the immediate neighbourhood.

Chemical banding by the rhythmic precipitation of colloidal iron oxide occurs in patches in the Tertiary limestones and calcareous clays as at the Amphitheatre, at the Rutledge's Creek coastal section, and in the cliffs near Hennessy Steps (east of Broken Head).

In the Jurassic sediments outcropping in the south-eastern portion of the area, current bedding and honeycomb and cannon-ball structures have been brought into prominence by differential weathering.

Stratigraphical and Palaeontological Relationships.

Eocene.

The nature and relationship of the westerly dipping Eocene beds, with a strong littoral fauna, S.E. of the Gellibrand River mouth, have already been described (1, 30, 33). Since that description, W. J. Parr has found an outcrop of fossiliferous, glauconitic clay at a locality about 1 mile N.W. of Pebble Point, near the two recorded bands of sandstone, one containing *Turritella* sp. and the other *Trochocyathus* with *Odontaspis*. Foraminifera, corals, pelecypods, gasteropods, scaphopods and shark's teeth occur in the glauconitic clay. Mr. Parr has examined

the foraminifera and concluded that the assemblage is similar to that in the Pebble Point Beds (Eocene). This evidence lends further proof to the conclusion drawn from the lithological character and disposition of the sediments immediately above the Pebble Point Beds (1), that they are also of Eocene age. The Eocene deposits south-east of the Gellibrand River, therefore, include the Pebble Point Beds and the overlying fossiliferous clays with intercalated sandstone beds, up to the base of the non-fossiliferous sandy clays and ferruginous sandstones which occur half a mile south-east of Point Ronald.

(?)Oligocene.

Unfossiliferous beds immediately above the Eocene, which have the same dip in the same direction as the Eocene deposits, may be of Oligocene age, but there is as yet no conclusive evidence to establish this. A bed of carbonaceous sandstone in this series bears certain lithological resemblances to carbonaceous sandstone at Anglesea in Victoria, but does not contain *Odontaspis contortidens* (Ag) or *Cyclammina*, which have been recorded from the Anglesean series, classed as Oligocene (29). The lowest (unfossiliferous) beds of the westerly dipping Tertiary deposits on the other side (i.e., north-west) of the Gellibrand River have no counterparts among those of unproven age which rest conformably upon the Eocene. This, and the fact that the direction and amount of dip are similar for outcrops on each side of the river mouth, lead to the assumption that the oldest beds exposed N.W. of the Gellibrand are younger than the youngest beds exposed S.E. of the river. This again, however, is not conclusive, because nothing is known of the beds or structures that existed in the gap created in the Tertiary rocks by the pre-Pleistocene ancestor of the Gellibrand River. If a continuous series of westerly-dipping beds is hidden beneath the Quaternary deposits at this locality, it should, according to calculations, be some 350-400 feet thick.

Miocene.

Extending for a distance of 2 to 2½ miles west of the mouth of the Gellibrand River, various exposures of the Tertiary beds form the lower 30 to 40 feet of the cliffs, but in many places between Point Ronald and Glenample Steps are obscured by large talus deposits (Pl. III., fig. 9) derived mainly from Pleistocene dune limestone. The Pleistocene forms the upper parts of the cliffs from a few yards east of Glenample Steps to within 30 chains of Point Ronald (at the mouth of the Gellibrand River), after which it comes down to sea level and forms the entire cliffs at Point Ronald (fig. 3), and the wave-cut platform and reefs half-a-mile south-east of the mouth of the Gellibrand River.

Thirty chains west of the Gellibrand River mouth, Wilkinson (34) recorded east-dipping Tertiary rocks, and at a section 10 chains further west he found 7 feet of unfossiliferous, blue, sandy clay with a few quartz pebbles, overlain by 20 feet of yellow, red and grey sandy clay with no fossils. The author found that these are really west-dipping Tertiary beds at this locality (Pl. III., fig. 12). Half-a-mile north-west of Point Ronald, outcrops of Tertiary beds, occasionally visible among piles of large fallen blocks of dune limestone, consist of ferruginous gritty sandstone, about 15 feet thick at the base (lower limit hidden by Recent beach sands), with occasional bands of dense ironstone but no fossils visible in hand specimens. This is overlain by a lenticular bed 1-8 feet thick (Pl. III., fig. 11), containing abundant ferruginous pebbles 3-4 inches across, and ferruginous internal casts and external moulds of gasteropods like *Cypraea* sp., &c. On breaking, some of the pebbles are seen to contain casts of pelecypods. Sharks' teeth are also present in the matrix of the deposit. Wilkinson regarded the pebbles as rolled fragments of fossiliferous Miocene clays (34). Some of the matrix in which the pebbles are set consists of ferruginous gritty sandstone comparable to the underlying bed, and some of the pebbles are phosphatic. The fossil casts and moulds appear to belong to the deposit (i.e., not remanié), and are merely replaced by ironstone. Gritty limestone containing a band of ironstone 1 foot thick overlies the conglomerate, and forms part of the matrix in which the ferruginous, phosphatic nodules are set. A Janjukian shelly fauna occurs in this bed and in the overlying limestone. Forms such as *Graphularia senescens* (Tate), *Mopsea* cf. *coralloides* Ed. & H., *Flabellum distinctum* Ed. & H., various additional types of corals, *Paradoxechinus novus* Laube, *Lovenia forbesi* (T. Woods), echinoid spines, *Cellepora gambierensis* T. Woods, *Schizellozoon* sp., *Spondylus gaderopoides* McCoy, *Chlamys, Pallium* (*Mesopeplum*) aff. *palmipes* (Tate), *Willungia tasmanica* Powell, *Umbilia* cf. *platyrhyncha* (McCoy), *Conus* sp., and sharks' teeth, are present in this matrix. Additional features are large Nodosarians, well preserved Cidaroid spines, and round, brown-coloured grains of quartz about the size of a pea. The overlying gritty limestone is 15 to 20 feet thick, and contains abundant polyzoa and various echinoids, in addition to those fossils observed in the matrix of the ferruginous, phosphatic conglomerate. A few feet of fossiliferous clays, probably of Janjukian age, exposed above the gritty limestone, are overlain by Recent sands and talus. These clays contain a few species of foraminifera found in Janjukian beds in other parts of Victoria, but the greater part of the foraminiferal assemblage is composed of Balcombian species.

The outcrop of this series of beds can be traced along the beach section for about 40 yards. All of its members are conformable and dip 2½° westerly. At the north-west end of the exposure of ferruginous conglomerate and grits, fossiliferous blue and grey coloured clays appear. They are conformable with the beds containing macrofossils with a Janjukian aspect, and are westerly continuations of the clays resting upon the gritty limestone. The gritty limestone bed having a macro-fauna with Janjukian affinities may, with the clay immediately above it and the underlying non-fossiliferous beds, represent Upper Oligocene deposits, as Singleton (29) regards Janjukian beds as of Upper Oligocene to Lower Miocene age. There is no marked Batesfordian phase between the gritty limestone of Janjukian age, and the overlying conformable clays which grade into true Balcombian.

Further north-west of this locality, extending to about 2½ miles from Point Ronald, grey Tertiary clays form fairly steep cliffs 30 to 40 feet high (Pl. III., fig. 9). The clays in the cliff sections here are of Balcombian age, and extend north-west to the dipping Balcombian clays so prominently exposed in the high cliffs nearer Glenample Steps (Gibson's Beach). They contain abundant Balcombian fossils including, among others, foraminifera (see appendix), corals, polyzoa, rare brachiopods and rare echinoids, numerous molluscs among which are *Limopsis morningtonensis* Pritchard, *L. maccoyi* Chapman, *Glycymeris gunyoungensis* Chapman & Singleton, *Pterospira hannafordi* (McCoy), *Ellatrivia minima minima* (T. Woods), *Zoila platypyga* (McCoy), *Gigantocypraea gigas* (McCoy), *Dentalium mantelli* Zittel and *D. subfissura* (Tate), and *Aturia australis* (McCoy). Abundant small gasteropods are also present.

The clays and argillaceous limestones in the cliff sections south-east of Glenample Steps (i.e., at the locality referred to in earlier works as "three miles west of the Gellibrand River mouth"), correspond with Wilkinson's No. 9 locality (34). They dip south of west at 5° at the eastern end of the exposures, but the angle of dip decreases to 2° at the first headland east of Glenample Steps. The beds become horizontal near Glenample Steps and remain more or less so for over 20 miles in a westerly direction along the coastline, after which they dip westerly at low angles.

The fossil species from the beds in the cliff sections three miles north-west of the mouth of the Gellibrand River, many (260) of which are listed by Tate and Dennant (32, p. 218-226) and by Dennant and Kitson (12), and the lithological characters of the beds are comparable to those of the Muddy Creek (Lower) and Balcombe Bay beds, which are regarded as of Middle Miocene

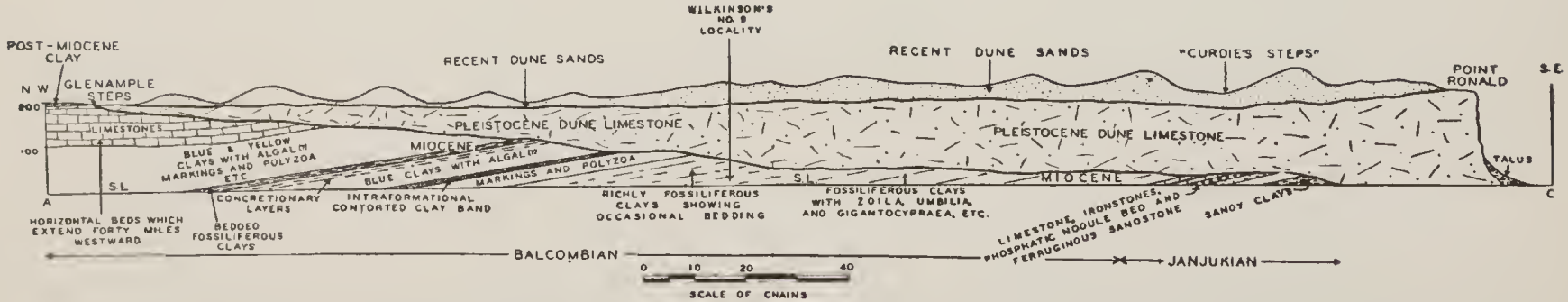

FIG. 3.—Geological Sketch Section, illustrating diagrammatically the coastal sections from Glenample Steps in the north-west to Point Ronald in the south-east. Length of section is just over 3½ miles. Heights above sea-level are up to 250 feet. The dip of the Tertiary beds is exaggerated.

age (29, p. 63-64). In parts, the clays are shale-like in appearance on account of the frequent parallel lineation of markings resembling algal remains. At this locality, a calcareous clay band containing *Umbilia eximia maccoyi* Schilder, *Umbilia leptorhyncha* (McCoy), *Zoila platypyga* (McCoy) and other gasteropods, occurs some 30 feet stratigraphically higher than another depositional phase of the clay containing *Cerithium apheles* T. Woods and *Gigantocypraea gigas* (McCoy). Between these two bands, and in the base of the cliffs further north-west of this locality, extending to Glenample Steps, the Lower Tertiary clays are chiefly blue-grey in colour. They contain numerous sinuous and concentric markings tentatively referred to as algal remains (Pl. III., fig. 7), a few species of foraminifera, *Ditrupa,* and sporadic patches with branching forms of polyzoa and molluscs. The curious branching and pipe-like markings which sometimes appear concentric in cross-sectional aspect, are alternating darker and lighter bluish-grey-coloured, laminated clay. They are often flattened, and although referred to as (?) algal markings, they do not show any definite plant-like structures. Dr. M. F. Glaessner has suggested to me the possibility of the markings being due to burrowing animals such as marine worms and the like. The remains of mud-haunting crabs and spatangoids in various parts of the Tertiary rocks suggest that the markings may be a result of their burrowing activities. Clays with similar markings occupy the base of the cliffs at Deany Steps, at Marble Arch, and immediately west of the mouth of the Sherbrook River where numerous echinoids (*Schizaster sphenoides* T. S. Hall, *Brissopsis tatei* T. S. Hall, *Maretia anomala* Duncan, *Eupatagus laubei* Duncan, &c.) and casts of *Turritella* sp. also occur. Balcombian clays similar to those occurring in the coastal sections north-west of Point Ronald, and equally rich in fossils, outcrop inland in small landslides (= Chapple's locality on the northern bank of Latrobe Creek, about half-a-mile from Princetown (9). At Deany Steps, (?) algal clays are exposed for at least forty feet above sea level. They overlie a narrow band of limestone, which forms the wave-cut platform here. This limestone is harder than the limestones higher up in the cliffs and is a pure form composed principally of minute foraminifera, gasteropods and occasional ostracods At Marble Arch, (?) algal clays also occur for forty feet upwards from the cliff base. They are overlain by friable limestones nearly white in colour, which represent leached portions of the younger limestone beds of the area. These beds contain Balcombian foraminifera.

Resting upon the (?) algal clays are shelly calcareous clays, argillaceous limestones and purer forms of soft and friable limestones (see upper part of Sentinel Rock in Plate II., fig. 2), which are only accessible in a few localities along the coastline, as at Rutledge's Creek, mouth of the Sherbrook River, the Amphitheatre, Deany Steps, London Bridge and Marble Arch. Because of the inaccessible nature of the intervening portions of the cliff sections, little can be said of the detailed characters of the sediments, but distant observations from the tops of the cliffs indicate no apparent variation in their nature from place to place. A detailed study of the more readily, but limited, accessible portions is, therefore, regarded as being sufficiently representative of the upper beds in general. Along portions of the coastline, fallen blocks from the higher parts of the vertical cliffs provide examples of fossils unrecorded from other localities in this part of the area. Thus, an example of *Paradoxechinus* was obtained from a fallen limestone block on Gibson's Beach. The stalk-eyed crab, *Ommatocarcinus coriocnsis* (Cresswell), which had previously been found at Two Mile Bay, associated with a few brachiopods and mud-haunting spatangoids (15), is a relatively common species in the (?) Balcombian limestones of the Port Campbell cliffs, occurring at Beacon Steps, Sherbrook River beach cliffs, Amphitheatre, Gravel Point, Rutledge's Creek, London Bridge, cliffs opposite Sentinel Rock, &c., where they have been collected both in situ and from fallen blocks. The soft basal clays containing (?) algal remains at the base of the cliffs in other accessible parts of the area are represented in the cliffs of Loch Ard Gorge by a dark indurated clayey rock containing examples of *Brissopsis tatei* T. S. Hall and *"Magellania."* Above this is a band of similar rock with patches containing abundant remains of *Ditrupa,* 15 to 20 feet above sea level. The lower beds in the cliffs are here overlain by limestones and argillaceous limestones.

At the Rutledge's Creek coastal section (= Wilkinson's No. 10 locality), where the beds are stratigraphically higher than the Gellibrand Clays by some 100 to 150 feet or more, a whitish to cream coloured limestone forming the wave-cut platform occurs in the base of the cliffs for up to about 6 feet above sea level. It is overlain by 10 to 15 feet of calcareous clay rich in molluscan and foraminiferal remains, and also containing numerous brachiopods, a few polyzoans, scaphopods, echinoids and cetacean bone fragments. Dr. F. A. Singleton has identified *Eotrigonia semiundulata* (Jenkins) and *Neotrigonia acuticostata* (McCoy) from this calcareous clay; both of these forms occur at the same level in a prominent storm notch (Pl. II., fig. 1), but elsewhere in Victoria they usually, though not always, occur on different horizons in the Tertiary series. Mr. O. P. Singleton has identified *Nototrivia subtilis* Schilder and *Ellatrivia minima*

(T. Woods), both of which are Balcombian species, from the Rutledge's Creek clay. The macro- and micro-fossil organisms from this clay are generally comparable with the fossil assemblage of the Gellibrand Clays (Balcombian), the main differences being the greater prominence of large cowries in the Gellibrand Clays, and the presence of the two forms of Trigonia and a few additional genera (usually indicating a younger age elsewhere in Victoria), in the Rutledge's Creek Clays. The calcareous clays at the Rutledge's Creek coastal section thus appear to constitute a slightly later phase than the typically Balcombian Gellibrand Clays. Above the calcareous clay band at Rutledge's Creek occur 10 to 15 feet of argillaceous limestone, then 20 feet of friable limestone, followed by 50 feet of soft, but purer forms of limestone (see Table 3). The Tertiary series here is covered by a veneer of post-Miocene clay deposits about 5-10 feet thick. The limestone beds in the upper parts of the cliffs are not as rich in fossils as the calcareous clays, but contain a few Balcombian species of foraminifera and scattered examples of *Brissopsis tatei* T. S. Hall, *"Magellania," Serripecten yahlensis semilaevis* (T. Woods), polyzoa and crab remains. Additional fossil genera from the limestone beds of other parts of the Port Campbell district are the large echinoid *Linthia compressa* (Duncan), found high up in the cliffs at the Grotto, *Lovenia forbesi* (T. Woods) in the upper parts of the cliffs at the Amphitheatre, Broken Head, Sherbrook River beach, Castle Rock, Point Hesse and Peterborough (Wilkinson's No. 11 locality), *Clypeaster cf. gippslandicus* McCoy at 45 feet above sea level at Hennessy Steps, at 15 feet above sea level on the west bank at the mouth of Rutledge's Creek, and 54 feet above sea level in a prominent notch at the Amphitheatre. One example of *Isurus* was found in the clays of post-Miocene age on the Tertiary limestones at Gravel Point; this form has a matrix of limestone identical with the limestone of the underlying Tertiary beds, and is therefore a remanié fossil derived from the Tertiary rocks.

The limestones of the Port Campbell coastal sections extend inland for some considerable distance. Outcrops of limestone and calcareous clays which occur at greater heights at Timboon, Curdie Vale, Jancourt and elsewhere contain foraminiferal assemblages similar to those in the Port Campbell limestones and clays. *Ellatrivia minima torquayensis* Schilder has been identified by Mr. O. P. Singleton from a specimen in the T. S. Hall collection collected inland from clays near the Port Campbell cheese factory. The prominent harder patches and sheets in the more friable limestones exposed in the coastal and inland sections sometimes contain similar fossils to those in the limestones. Dense, fine-grained portions are composed of echinoid spines and minute foraminifera, included in a dense calcareous base

stained in parts by limonite, and containing a few angular quartz grains. Such portions in the limestones are of concretionary character, and are partly of secondary origin.

At the Amphitheatre, one-half to three-quarters of a mile west of the Rutledge's Creek coastal section, the lower 30-35 feet of the cliff is inaccessible, but in the hanging valley of Ingle's Creek, bluish-grey coloured clays with "*Magellania*" underlie a hard calcareous band. This hard band is some six feet or so above the creek bed. Immediately underneath it *Ditrupa* is common. Above the hard calcareous band are some 65 feet of Tertiary sediments, starting with argillaceous limestone, from which *Schizaster sphenoides* T. S. Hall was obtained, and followed by a narrow bed of limestone, rich in comminuted shell fragments as well as complete shells. Overlying this is a layer showing well-developed chemical banding by iron oxide and a few fossils; this in turn is overlain by limestones with a calcareous clay band containing *Scutellina patella* Tate, *Brissopsis tatei* T. S. Hall, polyzoans, *Magellania garibaldiana* (Duncan), *Ostrea* sp., *Serripecten yahlensis semilævis* (T. Woods), *Cucullaea coriocnsis* McCoy, *Volutospina antiscalaris* (McCoy), *Dentalium mantelli* Zittel, &c. These are abundant on the east side of the Amphitheatre, in the face of a well-marked notch some six feet in height from floor to roof. The foraminiferal assemblage and many of the macro-fossils in this notch, which is 54 feet above sea level, are similar to those in the notch some ten feet or so above sea level at the Rutledge's Creek coastal section. The difference in height in these two instances is due to either faulting or local warping of the Tertiary sediments. Above the calcareous clay band at the Amphitheatre are about 50 feet of argillaceous and purer forms of limestones. They contain sporadic occurrences of fossil species similar to those in the notch. Among these higher beds is another band rich in *Ditrupa,* overlain by a bed of limestone with occasional small pellets of glauconite. Ten to 15 feet of post-Miocene clays and Recent soils cap the Tertiary deposits at this locality.

The height of the lower Ditrupa beds at the Amphitheatre is 45 feet above sea level, the same height as occurrences at the top of the third storm bench above sea level at Hennessy Steps (a few yards east of Broken Head), where associated fossil forms are numerous branching and disc-shaped polyzoans and occasional echinoids. Chapman (3, p. 30) and Chapman and Crespin (5) attached some importance to the occurrence of *Ditrupa* in Victoria, stating that it was typical of Victorian Janjukian beds. Since the Ditrupa beds in the Port Campbell district are stratigraphically higher than the Gellibrand Clays, which are of Balcombian age (29), then the Janjukian beds would, on these views, be above the Balcombian beds. Singleton, however,

places the Balcombian above the Janjukian (29), and this is the condition near Princetown. Accordingly, the Ditrupa beds must be late Balcombian or younger because the typical Balcombian deposits exposed in the coastal sections of this region are considerably lower on the stratigraphical scale, occurring as dipping beds some miles further to the south-east, at the locality three miles north-west of the mouth of the Gellibrand River. Ditrupa cannot be regarded, therefore, as typically Janjukian in this area. Determinations of the foraminifera by Mr. W. J. Parr (see appendix) indicate that the majority of the Tertiary beds in the Port Campbell district, north-west and west of the Gellibrand River belong to the Miocene (Balcombian) era of the Tertiary division. Preliminary examination of the molluscs by Dr. F. A. Singleton indicates that the Gellibrand Clays are Balcombian, while stratigraphically higher clays at Rutledge's Creek have a mixed fauna, principally Balcombian, but with some forms suggesting Cheltenhamian affinities.

Post-Miocene.

Clays of still younger age than the Miocene deposits of the district have been designated post-Miocene clays. They rest upon the upper limestones of the Tertiary series, varying in thickness from 2 to 20 feet. The contact with the underlying Miocene beds appears to be in the nature of a disconformity, with an apparent old erosion surface in the Tertiary rocks, formed parallel to the more or less horizontal bedding planes in the Tertiary sediments (see Pl. II., fig. 3). This, however, is not the true explanation, as the post-Miocene clays are most likely residual clays formed from the dissolution of younger horizons of the Tertiary limestones. These clays are yellow, red, brown and bluish-grey in colour; the variable colouration arising from different degrees of iron staining and leaching. They are compact with rare, well-rounded pebbles of reef quartz and quartzite, occasional aboriginal flints, and a certain amount of sand. They are frequently associated with abundantly developed buckshot gravel which occurs both at the surface, and at depths of 18 inches below the top of the clays. Occasional mounds of massive hydrous iron oxide are also associated with these clays at Gravel Point, Point Hesse and elsewhere. The iron oxide in such deposits was probably derived from iron salts that are present in most natural waters; it is doubtful whether sufficient could have been derived from the Tertiary sediments in the immediate neighbourhood. The post-Miocene clays contain remanié fossils derived from the Miocene limestones, and also occasional hard, nodular fragments of the limestone. The remanié fossils occur as fragments of *Serripecten, Magellania, Cellepora*, &c., which show signs of destruction by solution. The clays were, therefore, formed as residual deposits from the solution and weathering

of the higher members of the Miocene limestone series. This conclusion is supported by the fact that the limestones contain a certain percentage of clay constituents in their composition (see Table 3).

The post-Miocene clays nowhere come into contact with the Pleistocene dune limestone, consequently their age relationships can only be inferred from physiographical evidence. The past topography of the area was such that it appears likely that the post-Miocene clays had commenced to form before the ancestor of the Gellibrand River had eroded the wide valley in the Tertiary rocks, in which the Pleistocene dune limestone was ultimately deposited.

Pleistocene.

The Pleistocene dune limestone was deposited in at least three main stages. Murray records red sand beds about one or two feet thick between the calcareous sandstone beds, separating the series into layers 15, 40 and 50 feet thick, respectively (23, p. 129). Such interbedded material has come to be regarded in Victoria as representative of fossil soil horizons. The red bands are of limited lateral extent, occurring for no more than 200 yards in the Dune Cliffs at Princetown. Where they cut out, distinct breaks, representing bedding planes, continue between layers containing narrow bands (Pl. II., fig. 5), dipping at different angles (maximum 30°). As many as six such breaks are present in the river cliffs on the west bank of the Gellibrand River, about 300 yards from the river mouth, so there may be this number of depositional stages in the Pleistocene dune limestone. These stages are probably due to various eustatic changes of sea level during the Pleistocene Ice Age. The dune limestone shows the usual marked current bedding characteristic of similar rocks elsewhere in Victoria. It consists principally of comminuted shell waste, loosely cemented by secondary calcium carbonate, and is consequently of a porous nature. The degree of shell comminution and grain sorting suggests that these deposits were developed on shell banks and shelly beaches, where changes in the strength and direction of marine currents were pronounced. Occasional secondary hard bands of limestone, one to three inches thick, have been precipitated along some of the bedding planes, and small patches of recently formed red soil (terra rossa) are associated with the dune limestone west of a small quarry near Princetown. These recent patches of red soil represent the insoluble residue of clay and other mineral matter, left behind at the surface in depressions, after solution of the dune limestone. They are, therefore, comparable in origin with the red sandy beds intercalated within the dune limestone, and with the clays of post-Miocene age overlying the Miocene limestones of the district.

Holocene.

Recent deposits in the Port Campbell coastal area are represented by sand dunes, sand ridges, beach sands, and loose rudaceous deposits of angular character. The latter are formed from the older rock types, and consist of fallen blocks of Tertiary clays and limestones in some parts, Pleistocene dune limestone in others, and in parts they contain fragments of ironstone. The larger, angular fragments are set in a matrix composed partly of material derived from the post-Miocene clays, partly of smaller constituents from the Tertiary rocks. These deposits form large talus cones at the cliff bases, and perched talus cones on ledges situated at various heights up the vertical cliff faces. Patches of duricrust occur on non-vegetated portions of some of the Recent sand dunes, such as near the mouth of the Sherbrook River, and immediately east of Glenample Steps. Recent marine silts and sands, in part fossiliferous (23), occur along the lower reaches of some of the larger streams in the area, mixed with river-borne silts, sands and gravels. A well sunk through the floor of Port Campbell Creek (near the tennis courts) by a local resident, Mr. John Hennessy, revealed first 18 feet of Recent sands, and then two feet of shelly clays; the well ended in sands a short distance below the clay, and the sands immediately above the clay bed are said to have contained ti-tree remains. Recent clays and a bed of conglomerate two feet thick, overlain by clay, dune sands and kitchen midden materials, have infilled a small valley east of the mouth of the Sherbrook River. The pebbles in the conglomerate consist almost entirely of rounded fragments derived locally from the harder Tertiary limestone beds, and a few rounded ironstone fragments. This conglomerate is 12 feet above sea level and represents an old storm beach. It has been partially scoured out by recent marine activity.

The following table (Table 2) is a summary of the sequence of events in the history of the area as interpreted from several accessible cliff sections of varying height. It includes estimates of the thicknesses of the beds, wherever obtainable. The sequence was determined from a traverse in the direction of dip along the coastal sections, i.e., from S.E. to N.W. and W.

Table 2.

Geological Sequence in the Port Campbell Coastal District.

(Based on Wilkinson's and the author's observations.)

1. Jurassic. Calcareous felspathic sandstones (arkoses) and mudstones with nodules, carbonised wood and occasional small patches of coal. Occurs in the coastal sections from Pebble Point to Moonlight Head.

2. Time Interval Extending Through the Cretaceous.

3. Eocene. (*a*) Grits, massive ironstones and sandy ironstones with quartz pebbles and fragments of Jurrassic rocks. Fossiliferous beds with *Cucullaea psephea, Lahillia australica, Limopsis* sp., *Nuculana pacigradata, Dentalium gracilicostatum, Aturoidea distans, Nautilus victorianus, Callianassa* sp., Shark's teeth and fossil wood.—50 feet.

(*b*) Black and greenish-coloured clay with sulphides, copiapite, a few quartz pebbles and occasional shelly fossils. In middle of clay beds, felspathic sandstone bands from east to west, (i) a band with echinoid and pelecypod casts, (ii) a band with *Turritella* sp. and *Ditrupa*, (iii) a band with *Odontaspis, Cycloseris* and *Trochocyathus*.—125 feet and over.

(*c*) Red and yellow sandy beds, ferruginous and non-fossiliferous.—35 feet.

(*d*) Black carbonaceous clays and sandy clays, with gypsum and copiapite in parts.—40 feet.

(*c*) and (*d*) may possibly be of Oligocene age. The beds in this sequence comprise the dipping strata south-east of the mouth of the Gellibrand River, and include Wilkinson's Nos. 6, 7, and 8 localities (34). The deposits total some 250 feet in thickness, according to Wilkinson, but are probably nearer 1,000 feet thick (1). They occur in the coastal sections between the Gellibrand River and Pebble Point.

4. Gap in Sequence of Tertiary Beds (Due to Post-Miocene Erosion) and Probably Representing Oligocence Time. Area Occupied by Pleistocene Dune Limestone.

5. Upper Oligocene-Miocene (Janjukian).

(i) *a*. Blue sandy clays with a few quartz pebbles, but no fossils.—7 feet.

b. Yellow, red and grey sandy clay, with no fossils.—20 feet.

These are west-dipping beds 40 chains north-west of the mouth of the Gellibrand River.

(ii) *a*. Ferruginous gritty sandstone.—15 feet.

b. Ferruginous phosphatic conglomerate, with abundant fossils.—3·8 feet.

c. Gritty limestone with corals, echinoids, polyzoa, pelecypods, &c.—15-20 feet.

d. Fossiliferous clays.—20 feet.

The beds in Section 5 (ii) dip westerly at low angles and occur 40-50 chains north-west of the mouth of the Gellibrand River. They comprise an older phase than the true Balcombian sediments, and appear to be Janjukian on the evidence of the shelly fossil content, but a transition phase between the Janjukian and the Balcombian from the evidence of the foraminifera.

6. Miocene (Balcombian).

Grey and blue coloured clays with a variable shelly fossil content and traces of bedding planes dipping westerly at 5 degrees, outcrop at intervals between localities 50 chains north-west and 3 miles north-west of the mouth of the Gellibrand River. At three miles north-west of the Gellibrand, the sequence is:—

(*a*) Blue, stiff clay with many molluscs, corals, polyzoa, &c.—40 feet

(*b*) Yellowish calcareous clay with few fossils.—32 feet.

The total thickness of this series of sediments is calculated at about 650 feet, from the fact that they dip at 4-5 degrees and outcrop over a distance of two miles.

7. Miocene (? Balcombian).

Horizontal limestones and calcareous clays, 100 feet thick in some parts, up to 300 feet thick in other parts.

(i) *a*. Hard, yellowish to cream coloured limestone with few fossils.—6 feet.

b. Calcareous, bluish-grey coloured clay, rich in fossils. Argillaceous limestone with few fossils.—30 feet.

c. Yellow and whitish-coloured limestones with a few fossils.—54 feet,

The beds in 7 (i) occur at the Rutledge's Creek coastal section.

(ii) *a*. Bluish-grey coloured clays.—36 feet.

b. Argillaceous limestone, shelly limestone, richly fossiliferous calcareous clay, purer forms of limestone with some fossils.—65 feet.

The beds in 7 (ii) occur at the Amphitheatre.

(iii) *a.* Bluish grey coloured clays.—40 feet.
b. Argillaceous limestones, calcareous clays and purer forms of limestones.—200 feet.

The beds in 7 (iii) occur at Deany Steps.

The sequence of beds in 7 (i), 7 (ii), and 7 (iii) is generally similar in the cliffs from Castle Rock in the south-east to within half a mile of the Grotto in the west. Variations in total thickness at each of the several cliff sections examined result from cliff height variations and local warping in parts.

(iv) Soft yellowish limestone with few fossils, resting on calcareous clays similar to those in 7 (i) *b* at the Rutledge's Creek coastal section.—30-40 feet.

The beds in 7 (iv) occur in the vicinity of Curdie's Inlet. The beds in 7 are younger phases of the Miocene beds. They are regarded as ?Balcombian, being stratigraphically higher than the Balcombian of the coastal sections 3 miles north-west of the Gellibrand River, and having a somewhat different fauna.

8. Post-Miocene. Red, brown, yellow and blue-grey sandy clays with remanié fossils. These extend along the tops of the cliff sections from Glenample Steps to the Grotto.—2-20 feet.

9. Pleistocene. Dune limestones of the Gellibrand River area.—Up to 300 feet.

10. Recent.—Unconsolidated dune sands, beach deposits, red soils, alluvium, duricrust, &c.

Lithology and Mineralogy of the Sediments.

The lithological and mineralogical characteristics of the Jurassic and Eocene beds S.E. of the mouth of the Gellibrand River have been dealt with elsewhere (1).

(?) Oligocene.

The sandy clay 30 chains N.W. of Point Ronald is a rather incoherent sediment which rapidly sludges in water. Seventy-one per cent. of the deposit consists of almost pure white quartz sand of even grade size, the grains being 0.2-0.8 mm. across. The quartz grains are well rounded, some are translucent, some are opaque, partly as a result of pitting by abrasion, very few are sub-angular or iron-stained. A small amount of andalusite and rare grains of both blue and brown tourmaline are present in addition to the minerals listed in Table 3. The ferruginous gritty sandstone from the cliff section half-a-mile north-west of the mouth of the Gellibrand River consists of rounded and angular quartz grains and limonite pellets with a few foraminifera, coral fragments, felspar grains, and quartzite fragments, set in a partly calcareous, partly ferruginous base. Similar materials occur in the matrix of the overlying ferruginous phosphatic conglomerate, which also includes matrix material identical with the overlying gritty limestone. The quartz grains in the limestone are up to 0.4 mm. long, opaque, white and translucent, and principally well-rounded. These are set in a calcareous base containing abundant micro-organisms—foraminifera, echinoid spines, &c., and fragments of polyzoa and shelly fossils. Fossil structures are partially replaced by ferruginous matter.

TABLE 3.—MINERAL COMPOSITIONS OF SOME PORT CAMPBELL ROCKS. (ROCK TYPES ARRANGED IN STRATIGRAPHICAL ORDER).

	Rock.	Locality.	Percentage Soluble Fraction.	Percentage Clay.	Percentage Sand.	Rounded Quartz.	Angular to Sub-Angular Quartz.	Felspar.	Mica.	Glauconite (Oolitic and/or Foram. Casts.)	Gypsum.	Ilmenite and/or Magnetite	Limonite.	Pyrite.	Tourmaline.	Cassiterite.	Zircon.	Rutile.	Number.
Quaternary.	Beach sand ..	Picnic Steps, 5 chains N. E.of Sentinel Rock	70	—	30	(x)	—	—	—	—	—	+	+	—	+	—	+	—	1
	Dune limestone ..	Quarry, 1 mile west of Princetown	93	tr.	7	(x)	+	+	—	—	—	+	+	—	+	—	+	+	2
	Duricrust	Mouth of Sherbrook River.. ..	70·5	0·7	28·8	(x)	+	—	—	—	—	+	+	—	+	+	+	—	3
	Post-Miocene clays ..	Broken Head	6	66·5	27·5	+	(x)	+	—	—	—	+	+	—	+	+	+	+	4
M. Miocene.	Soft limestone ..	88′ above sea level, Rutledge's Beach	91	8	1	+	(x)	+	—	+	+	+	—	—	+	—	+	+	5
	Soft limestone ..	73′ above sea level, Rutledge's Beach	85	13·5	1·5	+	(x)	+	—	+	—	+	+	—	+	—	+	—	6
	Friable limestone ..	40′ above sea level, Rutledge's Beach	86	14	tr.	+	(x)	+	—	—	+	+	+	—	+	—	+	—	7
	Argillaceous limestone	20′ above sea level, Rutledge's Beach	79	21	tr.	+	(x)	+	—	+	—	+	+	—	+	—	+	—	8
	Upper calcareous clay	12′ above sea level, Rutledge's Beach	53	47	tr.	—	+	+	+	+	—	+	+	—	—	—	—	—	9
	Harder whitish limestone	Wave platform, Rutledge's Beach ..	95	5	tr.	—	+	—	+	—	—	+	—	—	—	—	+	—	10
	Harder grey limestone	Wave platform, Deany Steps ..	98	2	tr.	—	+	—	—	—	—	+	—	—	—	—	—	—	11
	Lower calcareous clay	Beach section 2½–3 miles N.W. of Point Ronald	36	64	tr.	—	+	—	+	+	+	+	—	+	—	—	+	—	12
L. Miocene.	Lowest calcareous clay	50 chains N.W. of Point Ronald ..	37·5	62	0·5	—	+	+	+	+	+	+	+	+	+	—	+	—	13
	Gritty limestone ..	50 chains N.W. of Point Ronald ..	74·6	3·9	21·5	(x)	+	+	+	+	—	+	+	—	+	—	+	+	14
	Sandy clay.. ..	½ mile N.W. of Point Ronald ..	nil	29	71	(x)	+	—	—	—	—	+	+	—	+	—	+	+	15

(x) = more common type of quartz grains.

Table 3 illustrates the acid solubility and mineral content of the more readily accessible Tertiary and Quaternary rocks from various localities along the coastal sections in the Port Campbell-Princetown district. The soluble fraction is composed principally of calcium carbonate, but small amounts of soluble iron compounds are also present. The sand fractions are composed principally of quartz. The heavy minerals are only represented by one or two grains of each species, except for limonite and ilmenite, which are more frequent. The felspar consists of plagioclase, microcline and orthoclase-perthite; the mica is present as a few flakes of brown and bleached biotite. Most of the mineral species were derived from the Jurassic arkoses and mudstones which formed the adjacent coastline at the time of deposition of the Middle Tertiary sediments. A peculiarity of some of the clays from the dipping Tertiary beds, $2\frac{3}{4}$-3 miles north-west of the mouth of the Gellibrand River, is the ease and rapidity with which they sludge in water. The constituents of such clays are almost entirely under 0.2 mm. across.

Miocene.

In the lower calcareous clays from the cliff sections north-west of the Gellibrand, most of the soluble fraction is due to the abundance of foraminifera and polyzoa. Casts of some of these organisms remained after acid treatment. Quartz grains are few in number in these clays and are subangular in outline, with a maximum size of 0.1 mm. The clay content is greater in these rocks than in the other Tertiary lithological types, and is in part gypseous. Pyrite occurs as minute rounded pellets and rods, and as larger nodules up to 3 inches long.

The hard, grey-coloured limestone constituting the wave-cut platform at Deany Steps contains only a minute quantity of sand. Most of the small percentage of insoluble matter consists of minute clay particles. Small forms of foraminifera, polyzoa, molluscs and ostracods are set in a calcareous matrix in this limestone. The softer limestones in the cliffs at this locality contain occasional flints.

The limestone of the wave-cut platform at Rutledge's Creek has a somewhat greater percentage of insoluble matter (mainly clay) than that at Deany Steps, and is not of so compact a nature. The calcareous clay, 12 feet above sea level at Rutledge's Beach, is more calcareous than the stratigraphically lower calcareous clay three miles north-west of the mouth of the Gellibrand River, mainly because at the locality where it was sampled, a molluscan fauna is profusely developed. Above this clay, the beds in the cliffs at Rutledge's Beach grade into argillaceous limestone which becomes purer as the percentage of clay decreases in the limestones higher up the cliffs, where gypsum also appears in small quantities. The limestones forming the higher portions of the

cliffs in the Port Campbell district are fine-grained, the matrix being of clay grade in which complete, large and small fossil organisms are embedded.

A few glauconitic casts of foraminifera and other micro-organisms appear in the sand fraction of certain of the limestones and calcareous clays. In parts, the glauconite has been altered and replaced by limonite. A marked feature of portion of the limestone beds above the pronounced notch at the Amphitheatre is the abundance of small dark-coloured spots of glauconite, which proved to be pellets and micro-fossil casts.

Post-Miocene.

The post-Miocene clays contain a small proportion of soluble carbonate. One grain of garnet and one grain of cyanite were seen in addition to the minerals listed in Table 3 (No. 4). The larger grains of quartz are well rounded, the smaller ones are sub-angular, and some of the quartz is of amethystine colour. The range in size of the quartz grains is 0.02 to 0.5 mm. across. The comparative clay-sand content for the post-Miocene clay and the Tertiary limestone from which the post-Miocene clay was derived is as follows:—

Tertiary Limestone: 9 of sand to 1 of clay
Post-Miocene Clay: 1 of sand to 3 of clay.

Pleistocene.

The soluble fraction of the dune limestone in the Princetown district is comparable in amount with that for consolidated dune rock from Limestone Hill, Cashmore, in the Portland district (11). The dune limestone contains foraminiferal, polyzoal, echinoid and molluscan fragments. The sand grains are not as well rounded as in the beach sands of the district, and quartz is sometimes of amethystine colour, ranging in size from 0.05 to 1.25 mm. Numerous cavities occur between the sand grains in the rock, but there are areas where dense calcareous bands occur. Clear calcite frequently forms rims around some of the quartz grains, and infills cavities in some of the foraminifera and smaller forms of gasteropods. A thin section of the red sandy beds in the Pleistocene dune limestone reveals rounded quartz grains and fragmentary fossil organisms set in a limonite-stained calcareous base.

Recent.

In the duricrust from the sand dunes at the mouth of the Sherbrook River, quartz grains are abundant and well rounded. They are mainly colourless, but occasionally pink, and range in size from 0.2 to 1 mm. In the beach sands, the quartz grains are mostly well rounded, ranging in size from 0.4 to 1 mm., with the majority over 0.5 mm. across. It is therefore apparent that few of the quartz grains were derived from the post-Miocene

clays (0.02 to 0.5 mm.), most coming from the Jurassic sandstones and Pleistocene dune limestone. The soluble content of the beach sands is due to comminuted shell waste, echinoid spines, foraminifera, &c., many of which were derived from the fossiliferous Tertiary rocks in the cliffs.

Acknowledgments.

The laboratory investigations were carried out in the Geology Department, Melbourne University, with the consent of Professor H. S. Summers. The author is indebted to Mr. W. J. Parr for foraminiferal determinations and for deductions of age relationships of the Port Campbell Tertiary rocks from his studies of the assemblages of these micro-organisms. Thanks are also due to Dr. F. A. Singleton for a preliminary examination of the echinoid and molluscan content of the various members of the Tertiary rocks and for discussions of the geological relationships in the field. Mr. O. P. Singleton kindly identified the Cypraeacea. Wilkinson's unpublished geological sketch section was kindly made available by the Director of the Victorian Geological Survey, Mr. W. Baragwanath.

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Explanation of Plates.

PLATE II.

Fig. 1.—Horizontal Miocene (?Balcombian) calcareous clays overlain by limestones, Rutledge's Creek coastal section. The apparent dip of the beds is due to the uneven surface of the beach. The noticed clays at the cliff base are richly fossiliferous.

Fig. 2.—Conformable Miocene (?Balcombian) clays and limestones with low angle of dip in a south westerly direction at Sentinel Rock (= the Haystack), 236 feet high.

Fig. 3.—Miocene (?Balcombian) strata with horizontal bedding planes marked by calcareous sheets and nodules of secondary origin, and overlain by post-Miocene clays, Castle Rock.

Fig. 4.—Fossiliferous Balcombian calcareous clays dipping 3 degrees south of west, and overlain by Miocene (Balcombian) limestones and Pleistocene dune limestone. Three miles north-west of the mouth of the Gellibrand River.

Fig. 5.—Pleistocene dune limestone showing current bedding. Talus cone at base of dune limestone cliff, and unconsolidated calcareous dune sand (Recent) on terrace cut in Tertiary rocks 40 feet above sea level. Two and a half miles north-west of the mouth of the Gellibrand River.

Fig. 6.—Collapse structure—monoclinal fold caused by slumping of limestone beds into solution cave. Post-Miocene clays with buckshot gravel cap the Miocene limestones. Promontory on east side of the Grotto Bay.

Fig. 7.—Dark markings (? algal) in grey Balcombian clays. Three and a quarter miles north-west of the mouth of the Gellibrand River.

Fig. 8.—Intraformational contortion of Balcombian clays. Three and a quarter miles north-west of the mouth of the Gellibrand River.

Fig. 9.—Cliffs of Balcombian clays partially masked by talus deposits of Pleistocene dune limestone. Two and a quarter miles north-west of the mouth of the Gellibrand River.

Fig. 10.—Jointed Balcombian clays. Two and three-quarter miles north-west of the mouth of the Gellibrand River.

Fig. 11.—Janjukian beds with a low westerly angle of dip. Nodule bed below, and limestones, with ferruginous bands above. About 50 chains north-west of Point Ronald.

Fig. 12.—Westerly dipping ? Oligocene, non-fossiliferous sandy clays, half a mile north-west of Point Ronald.

Appendix.

The Foraminifera of the Tertiary Beds Exposed in the Coastal Sections between the Mouth of the Gellibrand River and Curdie's Inlet.

By W. J. PARR.

The material examined consisted of washings and selected specimens received from Mr. G. Baker, M.Sc., and four samples, one collected by Rev. George Cox, and the others by the writer. Details of these are as follows:—

SAMPLE. 1.—From gritty limestone, apparently largely bryozoal, ½ mile north-west of Point Ronald. (Coll. G. Baker, M.Sc.).

The material consists of bryozoa with numerous well-developed foraminifera, 58 species of which were recognized. The commonest are *Dentalina soluta*, *Guttulina problema*, *Globulina* sp., *Sigmoidella* sp. aff. *kaguensis*, *Cassidulina subglobosa*, *Cibicides* sp. aff. *pseudoungerianus*, and *Dorothia* sp. aff. *parri*. These are found in the Balcombian and the Janjukian of Victoria. Two other species which occur have a more limited distribution, *Discorbis* sp. nov. (of *D. bertheloti* group) being, with the exception of records from Waurn Ponds and Birregurra, known only from the Janjukian of Torquay, in which it is common, while *Calcarina* sp. aff. *verriculata* occurs in the Janjukian limestones at the mouth of Spring Creek.

Sample. 2.—Clays immediately overlying gritty limestone ½ mile north-west of Point Ronald. (Coll. G. Baker.)

The washings are rich in well-preserved foraminifera, of which 82 species were separated. All of the more common forms in Sample 1 are present in addition to *Sigmomorphina chapmani* (described from the Miocene limestone of Batesford), *Bulimina* sp. nov. (common in Tertiary of Castle Cove), *Discorbis* sp. nov. (same species as in Sample 1), *Spiroloculina canaliculata*, *Cyclammina* sp. cf. *complanata*, *Liebusella antipodum* (common in Janjukian of Torquay, also noted from Tertiary of Lake Gnotuk), and *L. rudis* (only Victorian record is from Balcombian). The bryozoan, *Otoniella cupola*, var. *spiralis* is also present.

Sample 3.—Selected foraminifera from clays in cliffs, west of "Curdie's Steps" about ¾ mile north-west of Point Ronald. (Coll. G. Baker.)

There are 22 species of foraminifera, the assemblage being a typically Balcombian one, including *Cibicides victoriensis* (very fine examples), *Ceratobulimina* (*Ceratocancris*) *hauerii*, var. *australis*, *Dorothia* sp. nov. aff. *karreri*, *Carpenteria proteiformis* and the usual miliolines.

Sample 4.—Selected foraminifera from dipping clays, 2¾-3 miles north-west of Point Ronald (mouth of Gellibrand River). (Coll. G. Baker.)

There are 17 species of foraminifera, including *Cibicides victoriensis* (very typical), *Ceratobulimina* (*Ceratocancris*) *hauerii*, var. *australis*, and other Balcombian species.

Sample 5.—Three miles north-west of mouth of Gellibrand River. (Coll. G. Baker.)

The washings consist principally of foraminifera with abundant *Globigerinae*. There are 58 species of foraminifera including *Uvigerina interrupta* (Balcombian, Recent), *Ehrenbergina* sp. nov. aff. *mestayeri* (Balc.), *Ceratobulimina* (*Ceratocancris*) *hauerii*, var. *australis* (Balc.), *Hofkerina semiornata* (Balc.), *Globigerinoides ruber* (common—the only previous Victorian Tertiary record is from the Miocene limestone of Batesford), *Globigerina dehiscens* (Balc.), and *Dorothia* sp. nov. aff. *karreri* (Balc.). There are also many examples of a peculiar form related to Jedlitchka's genus *Candorbulina*. This assemblage is undoubtedly Balcombian in age.

Sample 6.—Clays from Gibson's Beach, 3½ miles north-west of mouth of Gellibrand River. (Coll. Rev. G. Cox.)

Forty-six species of foraminifera. All are Balcombian forms. The only noteworthy species is *Miniacina miniacea*, which is known from Balcombe Bay, the lower beds at Muddy Creek, and the Batesford limestone.

Sample 7.—Hard grey argillaceous limestone from about 80 feet above base of cliff, up pathway at Gibson's Steps. (Coll. W. J. Parr.)

Forty-two species of foraminifera were recognized. The only species of note are *Cibicides* sp. aff. *victoriensis* (a Balcombian form) *Ceratobulimina* (*Ceratocancris*) *hauerii*, var. *australis* (Balc., common), *Liebusella rudis* (Balc., large typical specimens common), and *Textularia* sp. nov. aff. *carinata*. The age is Balcombian.

Sample 8.—Selected foraminifera and washings from clay at 12 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.) Other material collected by the writer from the same bed was also examined.

This material is rich in species of foraminifera, 138 being recognized. They include *Sigmomorphina* spp., *Bolivinella* sp. nov., *Pavonina triformis, Discorbis papillata* (Balc.), *D.* sp. aff. *corrugata* (previously known only from lower beds, Muddy Creek), *Cancris intermedia* (Balc.), *Cibicides* sp. aff. *victoriensis, Elphidium parri, E. subinflatum* (Batesford and lower beds, Muddy Creek), *Planispirinella exigua* (Balc. and Recent), *Biloculinella angusta* (Balc., and Janjukian of Torquay), *Textularia* sp. nov. aff. *carinata, Gaudryina collinsi* (Western Beach, Geelong, apparently Balcombian), *Carpenteria rotaliformis,* and *Dorothia* sp. nov. aff. *karreri* (Balc.). The bryozoan, *Otoniella cupola,* var *spiralis,* and the annelid, *Ditrupa,* also occur.

Sample 9.—Washings from argillaceous limestone at 20 feet above sea-level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

There are fourteen species of foraminifera, the only species at all common being *Cibicides* sp. aff. *pseudoungerianus, C. victoriensis* (Balc.), *Orbulina universa,* and *Textularia* sp. nov. aff. *carinata.* Fragments of the tubes of the worm *Ditrupa* and the coral *Mopsea* also occur.

Sample 10.—Washings from friable limestone at 40 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

There are 25 species of foraminifera, the predominant forms being the same as in Sample 6. Spines of a spatangoid sea urchin are common and there are a few bryozoans.

Sample 11.—Washings from soft limestone at 73 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

Thirty-one species of foraminifera were recognized, including *Cibicides* sp. aff. *pseudoungerianus, C. victoriensis, Globorotalia dehiscens,* and a new, large, smooth species of *Bolivina.*

The samples from the mouth of Rutledge's Creek represent two facies of the Balcombian, one argillaceous from low down in the cliffs, and the other calcareous from the upper portions of the cliffs.

Sample 12.—Selected foraminifera from Notch, 54 feet above sea level, Amphitheatre, about ¾ mile west of mouth of Rutledge's Creek. (Coll. G. Baker.)

Thirty-one species of foraminifera. They include *Sigmoidella kagaensis, Cancris intermedia, Cibicides* sp. nov. (occurs also at mouth of Rutledge's Creek, 12 feet above sea level), *C.* sp. cf. *victoriensis, Planispirinella exigua,* and *Dorothia* sp. nov. aff. *karreri.* The age is Balcombian.

Sample 13.—Washings from blue-grey calcareous clay at base of cliffs, Deany Steps. (Coll. G. Baker.)

There are 43 species of foraminifera, including *Ceratobulimina* (*Ceratocancris*) *haueri,* var. *australis, Epistomina elegans* (common), 3 spp. of *Globorotalia, Textularia* sp. nov. aff. *carinata* (common), and *Martinottiella bradyana.* A Balcombian age is indicated.

Sample 14.—Limestone from base of cliffs just west of mouth of Curdie's Inlet. (Coll. W. J. Parr.)

Thirty-nine species of foraminifera. The commonest forms are *Liebusella rudis, Sigmoidella* sp. aff. *kagaensis,* and *Elphidium parri.* The species are all found in the Balcombian.

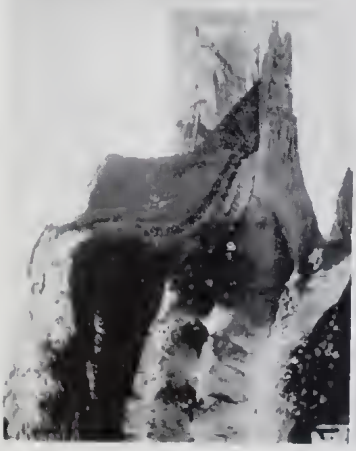
THE EVIDENCE OF THE FORAMINIFERA AS TO THE AGE OF THE DEPOSITS.

To sum up, it may be stated that, with the exception of Samples 1 and 2 from ½ mile north-west of the mouth of the Gellibrand River, the foraminifera in the samples examined indicate that the age of the beds from which they were collected is younger than the Janjukian and older than the Cheltenhamian. Some of the species are new, but the remainder in Samples 3 to 14 are forms which, according to the present state of our knowledge, are restricted to the Balcombian or are best represented in beds of that age. There are none of the restricted species of either the Janjukian or of the Cheltenhamian or higher beds. The larger foraminifera such as *Operculina, Amphistegina,* or *Lepidocyclina,* have not been found. *Hofkerina* and *Carpenteria,* with which they are generally associated, have, however, been met with and, as both are typically Balcombian in their occurrence, the absence of the other genera mentioned can be explained by the presence of conditions unfavorable to their existence.

Samples 1 and 2, from ½ mile north-west of Point Ronald, appear to be the oldest beds exposed, as the foraminifera include several species indicating a lower horizon than typical Balcombian. These species are referred to in the notes on the samples.

The term "Balcombian" as here used embraces the Batesfordian, as it has not been possible in the Port Campbell area to distinguish these two stages as defined by Dr. F. A. Singleton (29).

The total number of species of foraminifera recognized was 232.



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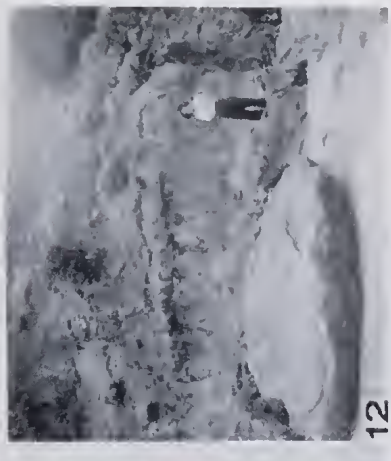
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